main_nb

April 23, 2025

[1]:

```
import numpy as np
import torch
import torch.nn as nn
import torch.optim as optim
import torchvision
import torchtune
import pickle as pkl
import os

from typing import Literal, Any
from tabulate import tabulate
from dataclasses import dataclass
from matplotlib import pyplot as plt
from tqdm import tqdm
from torchvision.transforms import v2
from torchvision.models import resnet50, ResNet50_Weights
from torchsummary import summary
from torchmetrics.classification import MulticlassAccuracy,␣
 ↪MulticlassPrecision, MulticlassRecall, MulticlassF1Score
```

```
WARNING:torchao.kernel.intmm:Warning: Detected no triton, on systems without
Triton certain kernels will not work
```

[2]:

```
device = torch.device("cuda" if torch.cuda.is_available() else "cpu")
print(f"Using device: {device}")
```

```
Using device: cuda
```

1 Data Loader

[3]:

```
IMG_DIM = 128
NUM_CHANNELS = 3
BATCH_SIZE = 512
NORMALIZE_MEAN = (0.485,0.456,0.406)
NORMALIZE_STD = (0.229,0.224,0.225)
NUM_CLASSES = 90
NUM_REAL_IMG_PER_CLASS = 60
NUM_AI_IMG_PER_CLASS = 30
```

```
REAL_IMG_TRAIN_PERCENTAGE = 0.5
REAL_IMG_TEST_PERCENTAGE = 0.5
```

[4]:

```
def get_subset_indices(
    num_img_per_class: int,
    percent: float = 1.0,
    side: Literal["left", "right"] = "left",
) -> np.ndarray:
    indices = []
    for i in range(NUM_CLASSES):
        base = i * num_img_per_class
        class_size = int(num_img_per_class * percent)
        start = 0 if side == "left" else num_img_per_class - class_size
        indices.extend(
            list(np.arange(base + start, base + start + class_size))
        )
    return np.array(indices, dtype=np.int32)
```

[5]:

```
def get_loader(
    real_img_dir: str = "./real_animals",
    ai_img_dir: str = "./ai_animals",
    real_img_percent: float = 1.0,
    ai_img_percent: float = 0.0,
    batch_size: int = BATCH_SIZE,
    num_workers: int = 0,
    shuffle: bool = True,
) -> tuple[torch.utils.data.DataLoader, torch.utils.data.DataLoader]:
    """
    Get train/test dataloaders for real and AI-generated images.
    """
    transform = v2.Compose([
        v2.Resize((IMG_DIM, IMG_DIM)),
        v2.ToImage(),
        v2.ToDtype(torch.float32, scale=True),
        v2.Normalize(mean=NORMALIZE_MEAN, std=NORMALIZE_STD),
    ])

    train_real_img_subset = torch.utils.data.Subset(
        torchvision.datasets.ImageFolder(
            root=real_img_dir,
            transform=transform,
            allow_empty=True,
        ),
        indices=get_subset_indices(NUM_REAL_IMG_PER_CLASS,␣
 ↪percent=REAL_IMG_TRAIN_PERCENTAGE * real_img_percent, side="left"),
    )
    test_real_img_subset = torch.utils.data.Subset(
        torchvision.datasets.ImageFolder(
            root=real_img_dir,
            transform=transform,
            allow_empty=True,
        ),
        indices=get_subset_indices(NUM_REAL_IMG_PER_CLASS,␣
↪percent=REAL_IMG_TEST_PERCENTAGE, side="right"),
    )
    ai_img_subset = torch.utils.data.Subset(
        torchvision.datasets.ImageFolder(
            root=ai_img_dir,
            transform=transform,
            allow_empty=True,
        ),
        indices=get_subset_indices(NUM_AI_IMG_PER_CLASS,␣
↪percent=ai_img_percent, side="left"),
    )

    train_dataset = torchtune.datasets.
↪ConcatDataset(datasets=[train_real_img_subset, ai_img_subset]) if␣
↪ai_img_percent > 0.0 else train_real_img_subset
    train_img_dataloader = torch.utils.data.DataLoader(
        dataset=train_dataset,
        batch_size=batch_size,
        shuffle=shuffle,
        num_workers=num_workers,
    )
    test_img_dataloader = torch.utils.data.DataLoader(
        dataset=test_real_img_subset,
        batch_size=batch_size,
        shuffle=shuffle,
        num_workers=num_workers,
    )

    return train_img_dataloader, test_img_dataloader
```

2 Models

2.0.1 CNN

[57]:

```
class CNN(nn.Module):
    def __init__(self, input_channels, n_classes):
        super(CNN, self).__init__()

        # set metadata
        self.input_channels = input_channels
        self.n_classes = n_classes
        self.FINAL_LAYER_SIZE = 4
        self.final_layer_channels = 40
        self.flatten_layer_size = self.final_layer_channels * self.
↪FINAL_LAYER_SIZE * self.FINAL_LAYER_SIZE

        # dropout layers
        self.dropout50 = nn.Dropout(p=0.5)
        self.dropout10 = nn.Dropout(p=0.1)

        # set up layers
        self.conv1 = nn.Conv2d(in_channels=input_channels, out_channels=8,␣
↪kernel_size=3, padding=1)
        self.pool1 = nn.MaxPool2d(kernel_size=2, stride=2)
        self.conv2 = nn.Conv2d(in_channels=8, out_channels=16, kernel_size=3,␣
↪padding=1)
        self.pool2 = nn.MaxPool2d(kernel_size=2, stride=2)
        self.conv3 = nn.Conv2d(in_channels=16, out_channels=24, kernel_size=3,␣
↪padding=1)
        self.pool3 = nn.MaxPool2d(kernel_size=2, stride=2)
        self.conv4 = nn.Conv2d(in_channels=24, out_channels=32, kernel_size=3,␣
↪padding=1)
        self.pool4 = nn.MaxPool2d(kernel_size=2, stride=2)
        self.conv5 = nn.Conv2d(in_channels=32, out_channels=self.
↪final_layer_channels, kernel_size=3, padding=1)
        self.pool5 = nn.MaxPool2d(kernel_size=2, stride=2)
        self.fc1 = nn.Linear(self.flatten_layer_size, 128)
        self.fc2 = nn.Linear(128, n_classes)

    def forward(self, x):
        # 1: conv -> pool
        x = self.conv1(x)
        x = self.dropout10(torch.nn.functional.leaky_relu(x))
        x = self.pool1(x)

        # 2: conv -> pool
        x = self.conv2(x)
        x = self.dropout10(torch.nn.functional.leaky_relu(x))
        x = self.pool2(x)

        # 3: conv -> pool
        x = self.conv3(x)
        x = self.dropout10(torch.nn.functional.leaky_relu(x))
        x = self.pool3(x)

        # 4: conv -> pool
        x = self.conv4(x)
        x = self.dropout10(torch.nn.functional.leaky_relu(x))
        x = self.pool4(x)

        # 5: conv -> pool
        x = self.conv5(x)
        x = self.dropout10(torch.nn.functional.leaky_relu(x))
        x = self.pool5(x)

        # flatten the features (the first dimension is batch size)
        x = x.view(-1, self.flatten_layer_size)

        # fc layers
        x = self.dropout50(torch.nn.functional.leaky_relu(self.fc1(x)))
        x = self.fc2(x)
        return x
```

[58]:

```
summary(CNN(input_channels=3, n_classes=NUM_CLASSES).to(device), (3, IMG_DIM,␣
 ↪IMG_DIM), batch_size=BATCH_SIZE, device=device.type)
```

```
----------------------------------------------------------------
        Layer (type)               Output Shape         Param #
================================================================
            Conv2d-1         [512, 8, 128, 128]             224
           Dropout-2         [512, 8, 128, 128]               0
         MaxPool2d-3           [512, 8, 64, 64]               0
            Conv2d-4          [512, 16, 64, 64]           1,168
           Dropout-5          [512, 16, 64, 64]               0
         MaxPool2d-6          [512, 16, 32, 32]               0
            Conv2d-7          [512, 24, 32, 32]           3,480
           Dropout-8          [512, 24, 32, 32]               0
         MaxPool2d-9          [512, 24, 16, 16]               0
           Conv2d-10          [512, 32, 16, 16]           6,944
          Dropout-11          [512, 32, 16, 16]               0
        MaxPool2d-12            [512, 32, 8, 8]               0
           Conv2d-13            [512, 40, 8, 8]          11,560
          Dropout-14            [512, 40, 8, 8]               0
        MaxPool2d-15            [512, 40, 4, 4]               0
           Linear-16                 [512, 128]          82,048
          Dropout-17                 [512, 128]               0
           Linear-18                  [512, 90]          11,610
================================================================
Total params: 117,034
Trainable params: 117,034
Non-trainable params: 0
----------------------------------------------------------------
Input size (MB): 96.00
Forward/backward pass size (MB): 2039.85
Params size (MB): 0.45
```

```
Estimated Total Size (MB): 2136.30
----------------------------------------------------------------
```

2.0.2 Combined Pre-trained

[59]:

```
def CombinedResNet50(frozen: bool = False) -> nn.Module:
    model = resnet50(weights=ResNet50_Weights.DEFAULT)
    if frozen:
        for param in model.parameters():
            param.requires_grad = False
    model.fc = nn.Linear(2048, NUM_CLASSES)
    return model
```

[60]:

```
summary(CombinedResNet50(True).to(device), (3, IMG_DIM, IMG_DIM),␣
 ↪batch_size=BATCH_SIZE, device=device.type)
```

```
----------------------------------------------------------------
        Layer (type)               Output Shape         Param #
================================================================
            Conv2d-1          [512, 64, 64, 64]           9,408
       BatchNorm2d-2          [512, 64, 64, 64]             128
              ReLU-3          [512, 64, 64, 64]               0
         MaxPool2d-4          [512, 64, 32, 32]               0
            Conv2d-5          [512, 64, 32, 32]           4,096
       BatchNorm2d-6          [512, 64, 32, 32]             128
              ReLU-7          [512, 64, 32, 32]               0
            Conv2d-8          [512, 64, 32, 32]          36,864
       BatchNorm2d-9          [512, 64, 32, 32]             128
             ReLU-10          [512, 64, 32, 32]               0
           Conv2d-11         [512, 256, 32, 32]          16,384
      BatchNorm2d-12         [512, 256, 32, 32]             512
           Conv2d-13         [512, 256, 32, 32]          16,384
      BatchNorm2d-14         [512, 256, 32, 32]             512
             ReLU-15         [512, 256, 32, 32]               0
       Bottleneck-16         [512, 256, 32, 32]               0
           Conv2d-17          [512, 64, 32, 32]          16,384
      BatchNorm2d-18          [512, 64, 32, 32]             128
             ReLU-19          [512, 64, 32, 32]               0
           Conv2d-20          [512, 64, 32, 32]          36,864
      BatchNorm2d-21          [512, 64, 32, 32]             128
             ReLU-22          [512, 64, 32, 32]               0
           Conv2d-23         [512, 256, 32, 32]          16,384
      BatchNorm2d-24         [512, 256, 32, 32]             512
             ReLU-25         [512, 256, 32, 32]               0
       Bottleneck-26         [512, 256, 32, 32]               0
           Conv2d-27          [512, 64, 32, 32]          16,384
      BatchNorm2d-28          [512, 64, 32, 32]             128
             ReLU-29          [512, 64, 32, 32]               0
           Conv2d-30          [512, 64, 32, 32]          36,864
      BatchNorm2d-31          [512, 64, 32, 32]             128
             ReLU-32          [512, 64, 32, 32]               0
           Conv2d-33         [512, 256, 32, 32]          16,384
      BatchNorm2d-34         [512, 256, 32, 32]             512
             ReLU-35         [512, 256, 32, 32]               0
       Bottleneck-36         [512, 256, 32, 32]               0
           Conv2d-37         [512, 128, 32, 32]          32,768
      BatchNorm2d-38         [512, 128, 32, 32]             256
             ReLU-39         [512, 128, 32, 32]               0
           Conv2d-40         [512, 128, 16, 16]         147,456
      BatchNorm2d-41         [512, 128, 16, 16]             256
             ReLU-42         [512, 128, 16, 16]               0
           Conv2d-43         [512, 512, 16, 16]          65,536
      BatchNorm2d-44         [512, 512, 16, 16]           1,024
           Conv2d-45         [512, 512, 16, 16]         131,072
      BatchNorm2d-46         [512, 512, 16, 16]           1,024
             ReLU-47         [512, 512, 16, 16]               0
       Bottleneck-48         [512, 512, 16, 16]               0
           Conv2d-49         [512, 128, 16, 16]          65,536
      BatchNorm2d-50         [512, 128, 16, 16]             256
             ReLU-51         [512, 128, 16, 16]               0
           Conv2d-52         [512, 128, 16, 16]         147,456
      BatchNorm2d-53         [512, 128, 16, 16]             256
             ReLU-54         [512, 128, 16, 16]               0
           Conv2d-55         [512, 512, 16, 16]          65,536
      BatchNorm2d-56         [512, 512, 16, 16]           1,024
             ReLU-57         [512, 512, 16, 16]               0
       Bottleneck-58         [512, 512, 16, 16]               0
           Conv2d-59         [512, 128, 16, 16]          65,536
      BatchNorm2d-60         [512, 128, 16, 16]             256
             ReLU-61         [512, 128, 16, 16]               0
           Conv2d-62         [512, 128, 16, 16]         147,456
      BatchNorm2d-63         [512, 128, 16, 16]             256
             ReLU-64         [512, 128, 16, 16]               0
           Conv2d-65         [512, 512, 16, 16]          65,536
      BatchNorm2d-66         [512, 512, 16, 16]           1,024
             ReLU-67         [512, 512, 16, 16]               0
       Bottleneck-68         [512, 512, 16, 16]               0
           Conv2d-69         [512, 128, 16, 16]          65,536
      BatchNorm2d-70         [512, 128, 16, 16]             256
             ReLU-71         [512, 128, 16, 16]               0
           Conv2d-72         [512, 128, 16, 16]         147,456
      BatchNorm2d-73         [512, 128, 16, 16]             256
             ReLU-74         [512, 128, 16, 16]               0
           Conv2d-75         [512, 512, 16, 16]          65,536
      BatchNorm2d-76         [512, 512, 16, 16]           1,024
             ReLU-77         [512, 512, 16, 16]               0
       Bottleneck-78         [512, 512, 16, 16]               0
           Conv2d-79         [512, 256, 16, 16]         131,072
      BatchNorm2d-80         [512, 256, 16, 16]             512
             ReLU-81         [512, 256, 16, 16]               0
           Conv2d-82           [512, 256, 8, 8]         589,824
      BatchNorm2d-83           [512, 256, 8, 8]             512
             ReLU-84           [512, 256, 8, 8]               0
           Conv2d-85          [512, 1024, 8, 8]         262,144
      BatchNorm2d-86          [512, 1024, 8, 8]           2,048
           Conv2d-87          [512, 1024, 8, 8]         524,288
      BatchNorm2d-88          [512, 1024, 8, 8]           2,048
             ReLU-89          [512, 1024, 8, 8]               0
       Bottleneck-90          [512, 1024, 8, 8]               0
           Conv2d-91           [512, 256, 8, 8]         262,144
      BatchNorm2d-92           [512, 256, 8, 8]             512
             ReLU-93           [512, 256, 8, 8]               0
           Conv2d-94           [512, 256, 8, 8]         589,824
      BatchNorm2d-95           [512, 256, 8, 8]             512
             ReLU-96           [512, 256, 8, 8]               0
           Conv2d-97          [512, 1024, 8, 8]         262,144
      BatchNorm2d-98          [512, 1024, 8, 8]           2,048
             ReLU-99          [512, 1024, 8, 8]               0
      Bottleneck-100          [512, 1024, 8, 8]               0
          Conv2d-101           [512, 256, 8, 8]         262,144
     BatchNorm2d-102           [512, 256, 8, 8]             512
            ReLU-103           [512, 256, 8, 8]               0
          Conv2d-104           [512, 256, 8, 8]         589,824
     BatchNorm2d-105           [512, 256, 8, 8]             512
            ReLU-106           [512, 256, 8, 8]               0
          Conv2d-107          [512, 1024, 8, 8]         262,144
     BatchNorm2d-108          [512, 1024, 8, 8]           2,048
            ReLU-109          [512, 1024, 8, 8]               0
      Bottleneck-110          [512, 1024, 8, 8]               0
          Conv2d-111           [512, 256, 8, 8]         262,144
     BatchNorm2d-112           [512, 256, 8, 8]             512
            ReLU-113           [512, 256, 8, 8]               0
          Conv2d-114           [512, 256, 8, 8]         589,824
     BatchNorm2d-115           [512, 256, 8, 8]             512
            ReLU-116           [512, 256, 8, 8]               0
          Conv2d-117          [512, 1024, 8, 8]         262,144
     BatchNorm2d-118          [512, 1024, 8, 8]           2,048
            ReLU-119          [512, 1024, 8, 8]               0
      Bottleneck-120          [512, 1024, 8, 8]               0
          Conv2d-121           [512, 256, 8, 8]         262,144
     BatchNorm2d-122           [512, 256, 8, 8]             512
            ReLU-123           [512, 256, 8, 8]               0
          Conv2d-124           [512, 256, 8, 8]         589,824
     BatchNorm2d-125           [512, 256, 8, 8]             512
```

```
            ReLU-126         [512, 256, 8, 8]               0
          Conv2d-127        [512, 1024, 8, 8]         262,144
     BatchNorm2d-128        [512, 1024, 8, 8]           2,048
            ReLU-129        [512, 1024, 8, 8]               0
      Bottleneck-130        [512, 1024, 8, 8]               0
          Conv2d-131         [512, 256, 8, 8]         262,144
     BatchNorm2d-132         [512, 256, 8, 8]             512
            ReLU-133         [512, 256, 8, 8]               0
          Conv2d-134         [512, 256, 8, 8]         589,824
     BatchNorm2d-135         [512, 256, 8, 8]             512
            ReLU-136         [512, 256, 8, 8]               0
          Conv2d-137        [512, 1024, 8, 8]         262,144
     BatchNorm2d-138        [512, 1024, 8, 8]           2,048
            ReLU-139        [512, 1024, 8, 8]               0
      Bottleneck-140        [512, 1024, 8, 8]               0
          Conv2d-141         [512, 512, 8, 8]         524,288
     BatchNorm2d-142         [512, 512, 8, 8]           1,024
            ReLU-143         [512, 512, 8, 8]               0
          Conv2d-144         [512, 512, 4, 4]       2,359,296
     BatchNorm2d-145         [512, 512, 4, 4]           1,024
            ReLU-146         [512, 512, 4, 4]               0
          Conv2d-147        [512, 2048, 4, 4]       1,048,576
     BatchNorm2d-148        [512, 2048, 4, 4]           4,096
          Conv2d-149        [512, 2048, 4, 4]       2,097,152
     BatchNorm2d-150        [512, 2048, 4, 4]           4,096
            ReLU-151        [512, 2048, 4, 4]               0
      Bottleneck-152        [512, 2048, 4, 4]               0
          Conv2d-153         [512, 512, 4, 4]       1,048,576
     BatchNorm2d-154         [512, 512, 4, 4]           1,024
            ReLU-155         [512, 512, 4, 4]               0
          Conv2d-156         [512, 512, 4, 4]       2,359,296
     BatchNorm2d-157         [512, 512, 4, 4]           1,024
            ReLU-158         [512, 512, 4, 4]               0
          Conv2d-159        [512, 2048, 4, 4]       1,048,576
     BatchNorm2d-160        [512, 2048, 4, 4]           4,096
            ReLU-161        [512, 2048, 4, 4]               0
      Bottleneck-162        [512, 2048, 4, 4]               0
          Conv2d-163         [512, 512, 4, 4]       1,048,576
     BatchNorm2d-164         [512, 512, 4, 4]           1,024
            ReLU-165         [512, 512, 4, 4]               0
          Conv2d-166         [512, 512, 4, 4]       2,359,296
     BatchNorm2d-167         [512, 512, 4, 4]           1,024
            ReLU-168         [512, 512, 4, 4]               0
          Conv2d-169        [512, 2048, 4, 4]       1,048,576
     BatchNorm2d-170        [512, 2048, 4, 4]           4,096
            ReLU-171        [512, 2048, 4, 4]               0
      Bottleneck-172        [512, 2048, 4, 4]               0
AdaptiveAvgPool2d-173        [512, 2048, 1, 1]               0
```

```
          Linear-174                  [512, 90]         184,410
================================================================
Total params: 23,692,442
Trainable params: 184,410
Non-trainable params: 23,508,032
----------------------------------------------------------------
Input size (MB): 96.00
Forward/backward pass size (MB): 15144.35
Params size (MB): 90.38
Estimated Total Size (MB): 15330.73
----------------------------------------------------------------

c:\Users\igort\AppData\Local\Programs\Python\Python312\Lib\site-packages\torchsummary\torchsummary.py:93: RuntimeWarning: overflow encountered in scalar add
  total_output += np.prod(summary[layer]["output_shape"])
```

3 Hyper Parameter Tuning

[6]:

```python
@dataclass
class Result:
    train_losses: list[float]
    avg_train_accuracies: list[float]
    test_losses: list[float]
    test_accuracies: np.ndarray
    avg_test_accuracies: list[float]
    test_precision: np.ndarray
    test_recall: np.ndarray
    test_f1score: np.ndarray
    avg_test_precision: float
    avg_test_recall: float
    avg_test_f1score: float

DIFF_METRICS = {
    "Train Accuracy": {
        "key": "avg_train_accuracies",
        "get_value": lambda x: x[-1]*100.0,
    },
    "Test Accuracy": {
        "key": "avg_test_accuracies",
        "get_value": lambda x: x[-1]*100.0,
    },
    "Test Precision": {
        "key": "avg_test_precision",
        "get_value": lambda x: x*100.0,
    },
    "Test Recall": {
        "key": "avg_test_recall",
        "get_value": lambda x: x*100.0,
    },
    "Test F1 Score": {
        "key": "avg_test_f1score",
        "get_value": lambda x: x*100.0,
    }
}
```

3.1 Visualizing Result Helpers

[7]:
```
def load_result(model_params: dict, with_details: bool = True) -> Result:
    details =␣
 ↪f"_{model_params["epochs"]}e_{str(model_params["learning_rate"])[2:
 ↪]}lr_{str(model_params["weight_decay"])[2:]}wd" if with_details else ""
    with open(f"./results/{model_params["name"]}{details}.pkl", "rb") as f:
        result = pkl.load(f)
    return result
```

[8]:
```
def save_result(result: Result, model_params: dict, with_details: bool = True)␣
 ↪-> None:
    details =␣
 ↪f"_{model_params["epochs"]}e_{str(model_params["learning_rate"])[2:
 ↪]}lr_{str(model_params["weight_decay"])[2:]}wd" if with_details else ""
    filepath = f"./results/{model_params["name"]}{details}.pkl"
    if os.path.isfile(filepath):
        print("Error: File already exists, not overwriting.")
        return
    with open(filepath, "wb") as f:
        pkl.dump(result, f)
```

[9]:
```
def print_basic_results(result: Result):
    print(f"Train Loss: {result.train_losses[-1]}")
    print(f"Train Accuracy: {result.avg_train_accuracies[-1] * 100}%\n")
    print(f"Test Loss: {result.test_losses[-1]}")
    print(f"Test Accuracy: {result.avg_test_accuracies[-1] * 100}%\n")
    print(f"Test Precision: {result.avg_test_precision * 100}%")
    print(f"Test Recall: {result.avg_test_recall * 100}%")
    print(f"Test F1 Score: {result.avg_test_f1score * 100}%")
```

[10]:
```
def plot_diff_table(results: dict[str, Result], title: str, metrics: dict[str,␣
 ↪dict[str, Any]]) -> None:
    metric_names = list(metrics.keys())
    values = []
    for result_name, result in results.items():
        row_array = [result_name]
        for _, metric in metrics.items():
            value = str(np.round(metric["get_value"](result.
↪__getattribute__(metric["key"])), decimals=4)) + "%"
            row_array.append(value)
        values.append(row_array)
    print(tabulate(values, headers=metric_names, tablefmt="rounded_grid"))
```

[11]:

```
def plot_loss_accuracy(result: Result) -> None:
    fig, ax = plt.subplots(nrows=1, ncols=2, figsize=(16, 4))
    fig.subplots_adjust(wspace=0.4)

    ax[0].set_title("Loss")
    ax[0].set_xlabel("Epoch")
    ax[0].plot(result.train_losses, label="Train Loss", color="blue")
    ax[0].plot(result.test_losses, label="Test Loss", color="red")
    ax[0].legend()
    ax[0].set_ylabel("Cross Entropy Loss")
    ax[0].grid(axis="both", linestyle="--", alpha=0.7)

    ax[1].set_title("Accuracy")
    ax[1].set_xlabel("Epoch")
    ax[1].plot(np.array(result.avg_train_accuracies)*100, label="Train␣
↪Accuracy", color="blue")
    ax[1].plot(np.array(result.avg_test_accuracies)*100, label="Test Accuracy",␣
↪color="red")
    ax[1].legend()
    ax[1].set_ylabel("Accuracy (%)")
    ax[1].grid(axis="both", linestyle="--", alpha=0.7)
```

[24]:

```
def plot_loss_accuracy_diff(result_left: Result, result_right: Result,␣
↪left_name: str, right_name: str) -> None:
    fig, ax = plt.subplots(nrows=1, ncols=2, figsize=(16, 4))
    fig.subplots_adjust(wspace=0.4)

    ax[0].set_title("Loss")
    ax[0].set_xlabel("Epoch")
    ax[0].plot(result_left.train_losses, label=f"{left_name}Train Loss",␣
↪color="blue")
    ax[0].plot(result_left.test_losses, label=f"{left_name}Test Loss",␣
↪color="red")
    ax[0].plot(result_right.train_losses, label=f"{right_name}Train Loss",␣
↪color="cyan")
    ax[0].plot(result_right.test_losses, label=f"{right_name}Test Loss",␣
↪color="orange")
    ax[0].legend()
    ax[0].set_ylabel("Cross Entropy Loss")
    ax[0].grid(axis="both", linestyle="--", alpha=0.7)
    ax[1].set_title("Accuracy")
    ax[1].set_xlabel("Epoch")
    ax[1].plot(np.array(result_left.avg_train_accuracies)*100,␣
  ↪label=f"{left_name}Train Accuracy", color="blue")
    ax[1].plot(np.array(result_left.avg_test_accuracies)*100,␣
  ↪label=f"{left_name}Test Accuracy", color="red")
    ax[1].plot(np.array(result_right.avg_train_accuracies)*100,␣
  ↪label=f"{right_name}Train Accuracy", color="cyan")
    ax[1].plot(np.array(result_right.avg_test_accuracies)*100,␣
  ↪label=f"{right_name}Test Accuracy", color="orange")
    ax[1].legend()
    ax[1].set_ylabel("Accuracy (%)")
    ax[1].grid(axis="both", linestyle="--", alpha=0.7)
```

[12]:

```
def plot_improvement_by_class(
    result_left: Result,
    result_right: Result,
    metric: Literal["test_accuracies", "test_precision", "test_recall",␣
  ↪"test_f1score"],
    classes: list[str],
    title: str = "Changes by Class",
    multiply_by: float = 1.0,
) -> None:
    fig, ax = plt.subplots(nrows=1, ncols=1, figsize=(16, 4))

    diffs = np.array(result_right.__getattribute__(metric) - result_left.
  ↪__getattribute__(metric))*multiply_by
    sorted_indices = np.argsort(diffs)
    diffs = diffs[sorted_indices]
    classes = np.array(classes)[sorted_indices]

    mask_positive = diffs >= 0
    mask_negative = diffs < 0

    negative = ax.bar(classes[mask_negative], diffs[mask_negative], color="red")
    ax.bar_label(negative, np.round(diffs[mask_negative], decimals=1),␣
  ↪label_type="edge", rotation=90)

    positive = ax.bar(classes[mask_positive], diffs[mask_positive],␣
  ↪color="green")
    ax.bar_label(positive, np.round(diffs[mask_positive], decimals=1),␣
  ↪label_type="edge", rotation=90)

    ax.tick_params(axis='x', labelrotation=90)
    ax.set_title(title)
    ax.set_xlabel("Class")
    ax.set_ylabel(f"Change in {metric.replace('_', ' ').title()}")

    diff_range = max(diffs) - min(diffs)
    ax.set_ylim(bottom=min(diffs) - 0.2*diff_range, top=max(diffs) + 0.
  ↪2*diff_range)
    ax.axhline(0, color="black", lw=1, ls="-")
```

[13]:
```
def plot_diff_barchart(results: dict[str, Result], title: str, metrics:␣
  ↪dict[str, dict[str, Any]]) -> None:
    metric_names = list(metrics.keys())
    x = np.arange(len(metrics))
    total_width = 0.5
    width = total_width / len(results)
    extra_spacing = 0.05*total_width
    offsets = np.linspace((-total_width/2) + (width/2) - extra_spacing,␣
  ↪(total_width/2) - (width/2) + extra_spacing, len(results))
    values = {}
    max_value = 0.0
    for result_name, result in results.items():
        for _, metric in metrics.items():
            if result_name not in values:
                values[result_name] = []
            value = metric["get_value"](result.__getattribute__(metric["key"]))
            values[result_name].append(value)
            if value > max_value:
                max_value = value

    fig, ax = plt.subplots(nrows=1, ncols=1, figsize=(16, 4))
    for i, result_name in enumerate(values):
        bars = ax.bar(x + offsets[i], values[result_name], width,␣
  ↪label=result_name)
        ax.bar_label(bars, np.round(values[result_name], decimals=1),␣
  ↪label_type="edge", rotation=90)

    ax.set_title(title)
    ax.set_xlabel("Metric")
    ax.set_ylabel("Percent (%)")
    ax.set_xticks(x, metric_names)
    ax.legend(ncols=3)
    ax.set_ylim(bottom=0, top=max_value + 0.2*max_value)
```

3.2 Main Training Function

[14]:
```
def train_and_test_model(
        model: nn.Module,
        optimizer: optim.Optimizer,
        train_loader: torch.utils.data.DataLoader,
        test_loader: torch.utils.data.DataLoader,
        E: int,
        verbose: Literal["none", "prints", "epoch_tqdm", "loader_tqdm"] =␣
 ↪"epoch_tqdm",
    ) -> Result:
    """
    Train and test the given model with the given parameters.
    """
    loss_function = nn.CrossEntropyLoss().to(device)

    accuracy_metric = MulticlassAccuracy(average='none',␣
 ↪num_classes=NUM_CLASSES).to(device)
    precision_metric = MulticlassPrecision(average='none',␣
 ↪num_classes=NUM_CLASSES).to(device)
    recall_metric = MulticlassRecall(average='none', num_classes=NUM_CLASSES).
 ↪to(device)
    f1_metric = MulticlassF1Score(average='none', num_classes=NUM_CLASSES).
 ↪to(device)

    train_losses = []
    avg_train_accuracies = []
    test_losses = []
    test_accuracies = 0
    avg_test_accuracies = []
    test_precision = 0
    test_recall = 0
    test_f1score = 0
    avg_test_precision = 0
    avg_test_recall = 0
    avg_test_f1score = 0

    for epoch in tqdm(range(E), total=E, disable=verbose!="epoch_tqdm"):
        # TRAINING
        model.train()
        batch_losses = []
        accuracy_metric.reset()
        for images, labels in tqdm(train_loader, total=len(train_loader),␣
 ↪disable=verbose!="loader_tqdm"):
            images, labels = images.to(device), labels.to(device)
            outputs = model(images)
            loss = loss_function(outputs, labels)
            optimizer.zero_grad()
            loss.backward()
            optimizer.step()
            batch_losses.append(loss.item())
            accuracy_metric.update(outputs, labels)
        train_loss = np.mean(np.array(batch_losses))
        train_losses.append(train_loss)
        train_acc = accuracy_metric.compute()
        avg_train_accuracies.append(train_acc.mean().item())

        # TESTING
        model.eval()
        test_batch_losses = []
        accuracy_metric.reset()
        precision_metric.reset()
        recall_metric.reset()
        for images, labels in tqdm(test_loader, total=len(test_loader), disable=verbose!="loader_tqdm"):
            images, labels = images.to(device), labels.to(device)
            outputs = model(images)
            test_batch_losses.append(loss_function(outputs, labels).item())
            accuracy_metric.update(outputs, labels)
            if epoch >= E - 1:
                precision_metric.update(outputs, labels)
                recall_metric.update(outputs, labels)
                f1_metric.update(outputs, labels)
        test_loss = np.mean(np.array(test_batch_losses))
        test_losses.append(test_loss)
        test_acc = accuracy_metric.compute()
        avg_test_accuracies.append(test_acc.mean().item())
        if epoch >= E - 1:
            test_accuracies = test_acc.cpu().numpy()
            test_precision = precision_metric.compute().cpu().numpy()
            test_recall = recall_metric.compute().cpu().numpy()
            test_f1score = f1_metric.compute().cpu().numpy()
            avg_test_precision = test_precision.mean().item()
            avg_test_recall = test_recall.mean().item()
            avg_test_f1score = test_f1score.mean().item()

        if verbose=="prints":
            print(f"Epoch [{epoch+1}/{E}]: Train Accuracy: {avg_train_accuracies[-1]*100:.2f}%, Train Loss: {train_loss:.4f}, Test Accuracy: {avg_test_accuracies[-1]*100:.2f}%, Test Loss: {test_loss:.4f}")

    print(f"\nEvaluation results:\nTrain Accuracy: {avg_train_accuracies[-1]*100:.2f}%, Train Loss: {train_loss:.4f}\nTest Accuracy: {avg_test_accuracies[-1]*100:.2f}%, Test Loss: {test_loss:.4f}")
    return Result(
        train_losses=train_losses,
        avg_train_accuracies=avg_train_accuracies,
        test_losses=test_losses,
        test_accuracies=test_accuracies,
        avg_test_accuracies=avg_test_accuracies,
        test_precision=test_precision,
        test_recall=test_recall,
        test_f1score=test_f1score,
        avg_test_precision=avg_test_precision,
        avg_test_recall=avg_test_recall,
        avg_test_f1score=avg_test_f1score,
    )
```

3.3 Tuning Code

[69]:

```
train_loader, test_loader = get_loader(real_img_percent=1.0, ai_img_percent=0.
  ↪0, num_workers=0)
```

[49]:

```
model_params = {
    "name": "combined_tune",
    "learning_rate": 0.001,
    "weight_decay": 0.001,
    "epochs": 20,
}
model = CombinedResNet50(frozen=True).to(device)
optimizer = optim.Adam(model.parameters(), lr=model_params["learning_rate"],␣
  ↪weight_decay=model_params["weight_decay"])
results_1 = train_and_test_model(
    model=model,
    optimizer=optimizer,
    train_loader=train_loader,
    test_loader=test_loader,
    E=model_params["epochs"],
    verbose="epoch_tqdm",
)
```

```
100%|          | 20/20 [17:04<00:00, 51.21s/it]


Evaluation results:
Train Accuracy: 99.81%, Train Loss: 0.2646
Test Accuracy: 85.78%, Test Loss: 0.8424
```

[ ]:

```
save_result(results_1, model_params, with_details=True)
```

```
Error: File already exists, not overwriting.
```

4 Evaluation

CNN Params

Learning Rate: `0.0001`; Weight Decay: `0.0075`; Epochs: `50`

Combined Pre-trained Params

Learning Rate: `0.001`; Weight Decay: `0.001`; Epochs: `20`

[76]:
```
def CNN_MODEL_PARAMS(name: str) -> dict:
    return {
        "name": f"cnn_{name}",
        "learning_rate": 0.0075,
        "weight_decay": 0.0001,
        "epochs": 50,
    }
def COMBINED_MODEL_PARAMS(name: str) -> dict:
    return {
        "name": f"combined_{name}",
        "learning_rate": 0.001,
        "weight_decay": 0.001,
        "epochs": 20,
    }
```

4.0.1 CNN

[119]:
```
train_loader, test_loader = get_loader(real_img_percent=0.5, ai_img_percent=1.
 ↪0, num_workers=0)
```

[120]:
```
cnn_model_params = CNN_MODEL_PARAMS("50real_100ai")
model = CNN(input_channels=NUM_CHANNELS, n_classes=NUM_CLASSES).to(device)
optimizer = optim.Adam(model.parameters(),␣
 ↪lr=cnn_model_params["learning_rate"],␣
 ↪weight_decay=cnn_model_params["weight_decay"])
cnn_result = train_and_test_model(
    model=model,
    optimizer=optimizer,
    train_loader=train_loader,
    test_loader=test_loader,
    E=cnn_model_params["epochs"],
    verbose="epoch_tqdm",
)
```

```
100%|          | 50/50 [57:23<00:00, 68.86s/it]


Evaluation results:
```

```
Train Accuracy: 49.11%, Train Loss: 1.7481
Test Accuracy: 15.33%, Test Loss: 4.3343
```

```
[121]: save_result(cnn_result, cnn_model_params, with_details=False)
```

4.0.2 Combined Pre-trained

```
[124]: train_loader, test_loader = get_loader(real_img_percent=1.0, ai_img_percent=0.
         ↪0, num_workers=0)
```

```
[125]: combined_model_params = COMBINED_MODEL_PARAMS("100real_0ai")
       model = CombinedResNet50(frozen=True).to(device)
       optimizer = optim.Adam(model.parameters(),␣
         ↪lr=combined_model_params["learning_rate"],␣
         ↪weight_decay=combined_model_params["weight_decay"])
       combined_result = train_and_test_model(
           model=model,
           optimizer=optimizer,
           train_loader=train_loader,
           test_loader=test_loader,
           E=combined_model_params["epochs"],
           verbose="epoch_tqdm",
       )
```

```
100%|     | 20/20 [17:15<00:00, 51.80s/it]


Evaluation results:
Train Accuracy: 99.78%, Train Loss: 0.2537
Test Accuracy: 85.48%, Test Loss: 0.8492
```

```
[126]: save_result(combined_result, combined_model_params, with_details=False)
```

5 Plot Results

```
[22]: CLASS_NAMES = []
      with open("./name_of_the_animals.txt", "r") as file:
          for line in file:
              CLASS_NAMES.append(line.strip())
```

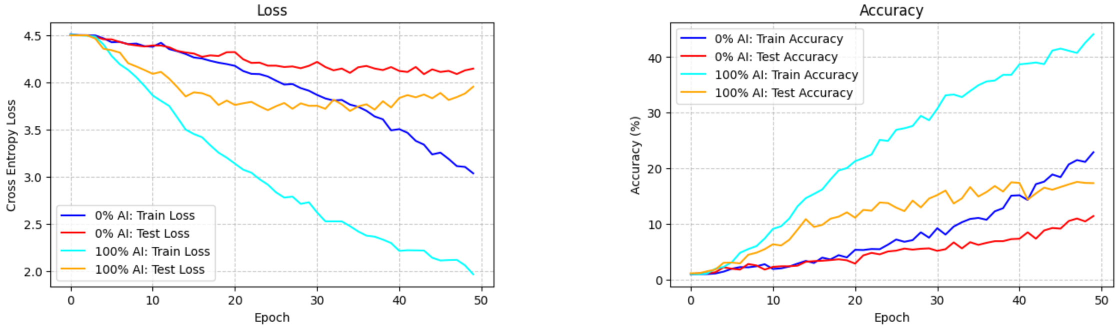
```
[15]: result_cnn_100real_0ai = load_result({"name": "cnn_100real_0ai"},␣
        ↪with_details=False)
      result_cnn_100real_50ai = load_result({"name": "cnn_100real_50ai"},␣
        ↪with_details=False)
```

```
result_cnn_100real_100ai = load_result({"name": "cnn_100real_100ai"},␣
  ↪with_details=False)
result_cnn_50real_100ai = load_result({"name": "cnn_50real_100ai"},␣
  ↪with_details=False)
result_cnn_0real_100ai = load_result({"name": "cnn_0real_100ai"},␣
  ↪with_details=False)
```

[16]:
```
result_combined_100real_0ai = load_result({"name": "combined_100real_0ai"},␣
  ↪with_details=False)
result_combined_100real_50ai = load_result({"name": "combined_100real_50ai"},␣
  ↪with_details=False)
result_combined_100real_100ai = load_result({"name": "combined_100real_100ai"},␣
  ↪with_details=False)
result_combined_50real_100ai = load_result({"name": "combined_50real_100ai"},␣
  ↪with_details=False)
result_combined_0real_100ai = load_result({"name": "combined_0real_100ai"},␣
  ↪with_details=False)
```

5.0.1 CNN

[25]:
```
plot_loss_accuracy_diff(
    result_cnn_100real_0ai,
    result_cnn_100real_100ai,
    "0% AI: ",
    "100% AI: ",
)
```

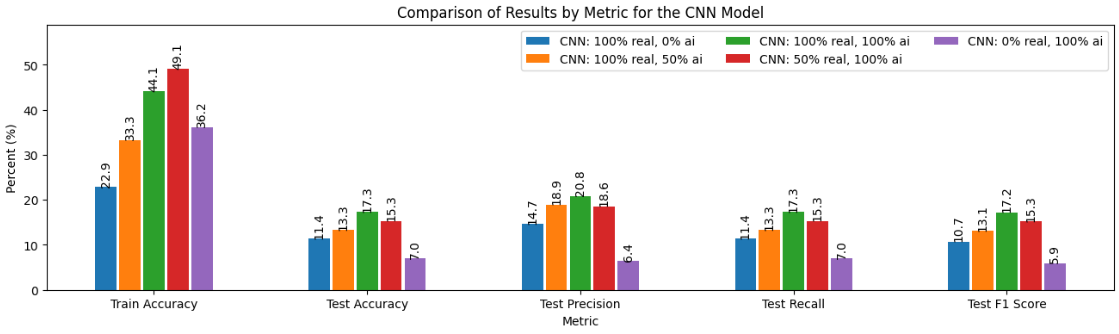


[20]:
```
plot_diff_table({
    "CNN: 100% real, 0% ai": result_cnn_100real_0ai,
    "CNN: 100% real, 50% ai": result_cnn_100real_50ai,
    "CNN: 100% real, 100% ai": result_cnn_100real_100ai,
    "CNN: 50% real, 100% ai": result_cnn_50real_100ai,
    "CNN: 0% real, 100% ai": result_cnn_0real_100ai,
}, "Comparison of Results by Metric for the CNN Model", DIFF_METRICS)
```

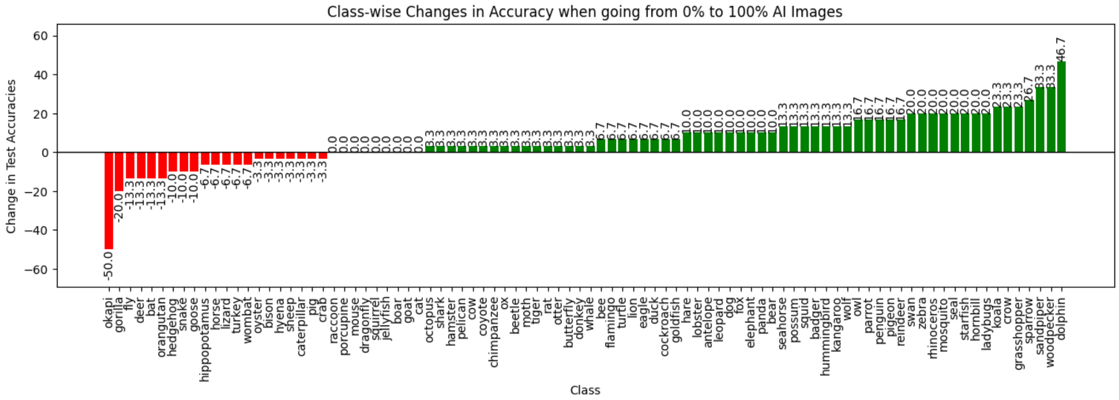
```
                          Train Accuracy     Test Accuracy     Test Precision  
Test Recall     Test F1 Score


CNN: 100% real, 0% ai     22.8889%           11.4074%          14.6854%
11.4074%        10.7273%


CNN: 100% real, 50% ai    33.3333%           13.3333%          18.9224%
13.3333%        13.1499%


CNN: 100% real, 100% ai   44.1296%           17.3333%          20.8278%
17.3333%        17.2135%


CNN: 50% real, 100% ai    49.1111%           15.3333%          18.5995%
15.3333%        15.2641%


CNN: 0% real, 100% ai     36.1852%           7.0%              6.3909%
7.0%            5.9042%
```

[33]:

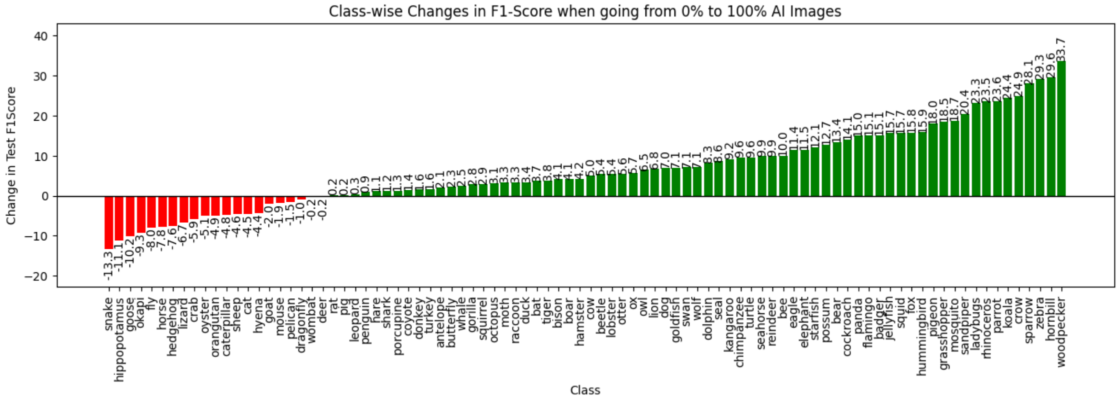
```
plot_diff_barchart({
    "CNN: 100% real, 0% ai": result_cnn_100real_0ai,
    "CNN: 100% real, 50% ai": result_cnn_100real_50ai,
    "CNN: 100% real, 100% ai": result_cnn_100real_100ai,
    "CNN: 50% real, 100% ai": result_cnn_50real_100ai,
    "CNN: 0% real, 100% ai": result_cnn_0real_100ai,
}, "Comparison of Results by Metric for the CNN Model", DIFF_METRICS)
```



```
[29]: plot_improvement_by_class(result_cnn_100real_0ai, result_cnn_100real_100ai,␣
      ↪"test_accuracies", CLASS_NAMES, "Class-wise Changes in Accuracy when going␣
      ↪from 0% to 100% AI Images", 100.0)
```

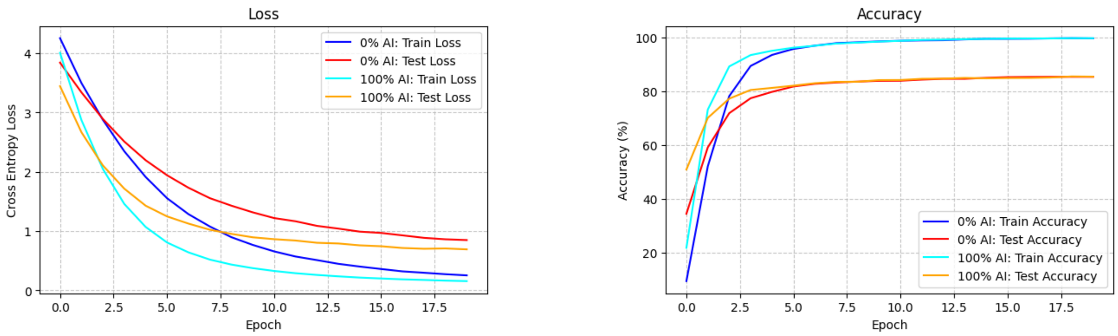


```
[34]: plot_improvement_by_class(result_cnn_100real_0ai, result_cnn_100real_100ai,␣
      ↪"test_f1score", CLASS_NAMES, "Class-wise Changes in F1-Score when going from␣
      ↪0% to 100% AI Images", 100.0)
```



5.0.2 Combined Pre-trained

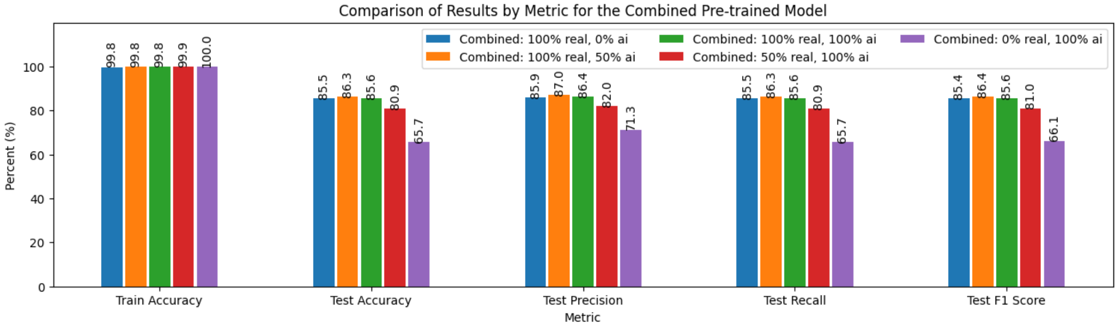
```
[26]: plot_loss_accuracy_diff(
          result_combined_100real_0ai,
          result_combined_100real_100ai,
          "0% AI: ",
          "100% AI: ",
      )
```



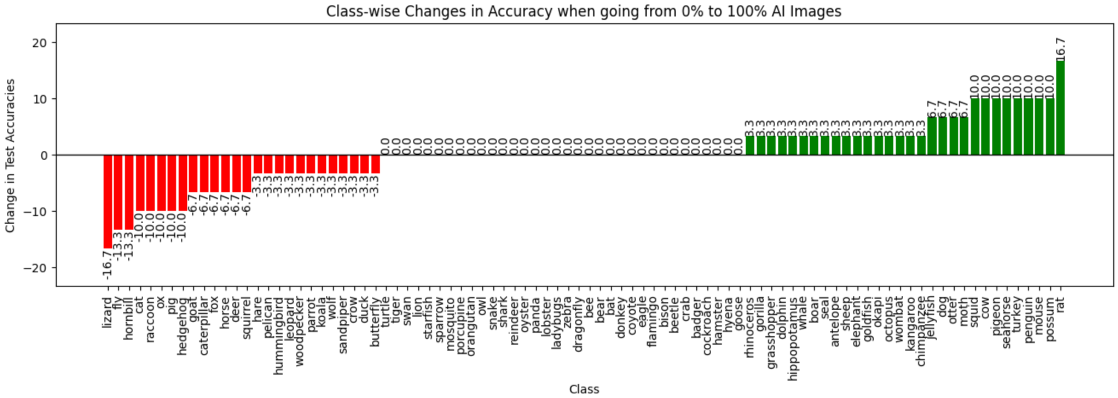
```
[27]: plot_diff_table({
          "Combined: 100% real, 0% ai": result_combined_100real_0ai,
          "Combined: 100% real, 50% ai": result_combined_100real_50ai,
          "Combined: 100% real, 100% ai": result_combined_100real_100ai,
          "Combined: 50% real, 100% ai": result_combined_50real_100ai,
          "Combined: 0% real, 100% ai": result_combined_0real_100ai,
      }, "Comparison of Results by Metric for the Combined Pre-trained Model",␣
       ↪DIFF_METRICS)
```

```
                               Train Accuracy     Test Accuracy     Test
Precision     Test Recall     Test F1 Score


 Combined: 100% real, 0% ai     99.7778%           85.4815%          85.9232%
 85.4815%          85.4437%


 Combined: 100% real, 50% ai    99.8025%           86.2963%          86.9619%
 86.2963%          86.3519%


 Combined: 100% real, 100% ai   99.8333%           85.5556%          86.3633%
 85.5556%          85.5986%


 Combined: 50% real, 100% ai    99.9012%           80.9259%          82.0247%
 80.9259%          80.9669%


 Combined: 0% real, 100% ai     99.963%            65.7037%          71.2748%
 65.7037%          66.1487%
```

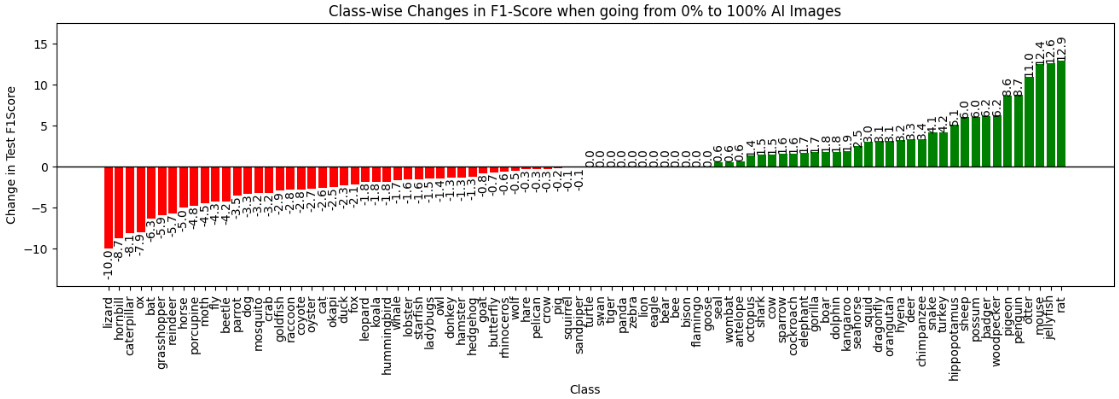
[28]:
```
plot_diff_barchart({
    "Combined: 100% real, 0% ai": result_combined_100real_0ai,
    "Combined: 100% real, 50% ai": result_combined_100real_50ai,
    "Combined: 100% real, 100% ai": result_combined_100real_100ai,
    "Combined: 50% real, 100% ai": result_combined_50real_100ai,
    "Combined: 0% real, 100% ai": result_combined_0real_100ai,
}, "Comparison of Results by Metric for the Combined Pre-trained Model",␣
↪DIFF_METRICS)
```



[30]:
```
plot_improvement_by_class(result_combined_100real_0ai,␣
↪result_combined_100real_100ai, "test_accuracies", CLASS_NAMES, "Class-wise␣
↪Changes in Accuracy when going from 0% to 100% AI Images", 100.0)
```



[32]:
```
plot_improvement_by_class(result_combined_100real_0ai,␣
↪result_combined_100real_100ai, "test_f1score", CLASS_NAMES, "Class-wise␣
↪Changes in F1-Score when going from 0% to 100% AI Images", 100.0)
```


Class-wise Changes in F1-Score when going from 0% to 100% AI Images
Change in Test F1Score
15
10
5
0
−5
−10
Class
lizard -10.0
hornbill -8.7
caterpillar -8.1
ox -7.9
bat -6.3
grasshopper -5.9
reindeer -5.7
horse -5.0
porcupine -4.8
moth -4.5
fly -4.3
beetle -4.2
parrot -3.5
dog -3.3
mosquito -3.2
crab -3.2
goldfish -2.9
raccoon -2.8
coyote -2.8
oyster -2.7
cat -2.6
okapi -2.5
duck -2.3
fox -2.1
leopard -1.8
koala -1.8
hummingbird -1.8
whale -1.7
lobster -1.6
starfish -1.6
ladybugs -1.5
owl -1.4
donkey -1.3
hamster -1.3
hedgehog -1.3
goat -0.8
butterfly -0.7
rhinoceros -0.6
wolf -0.5
hare -0.3
pelican -0.3
crow -0.3
pig -0.2
squirrel -0.1
sandpiper -0.1
turtle 0.0
swan 0.0
tiger 0.0
panda 0.0
zebra 0.0
lion 0.0
eagle 0.0
bear 0.0
bee 0.0
bison 0.0
flamingo 0.0
goose 0.0
seal 0.6
wombat 0.6
antelope 0.6
octopus 1.4
shark 1.5
cow 1.5
sparrow 1.6
cockroach 1.6
elephant 1.7
gorilla 1.7
boar 1.8
dolphin 1.8
kangaroo 1.9
seahorse 2.5
squid 3.0
dragonfly 3.1
orangutan 3.1
hyena 3.2
deer 3.3
chimpanzee 3.4
snake 4.1
turkey 4.2
hippopotamus 5.1
sheep 6.0
possum 6.0
badger 6.2
woodpecker 6.2
pigeon 8.6
penguin 8.7
otter 11.0
mouse 12.4
jellyfish 12.6
rat 12.9